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(54) Underwater seismic sources

(57) A method of modifying the radiated wave fields of a first non-resonant implosive marine source comprises firing, at a known time relative to the firing of the first source, a second non-resonant implosive marine source at a depth different from that of the first source, the depth of the second source being selected such that reflections of the wave fields of the first and second sources from the air-sea interface above the sources will at least partially cancel each other, thereby to decrease the effect of the reflection of the wave field from the air-sea interface upon the radiated wave field of the first source.

Preferably three or more implosive marine sources are fired each at a different depth to produce the desired modification, each implosive marine source being identical and comprising one or more water guns.

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FIG. 1.

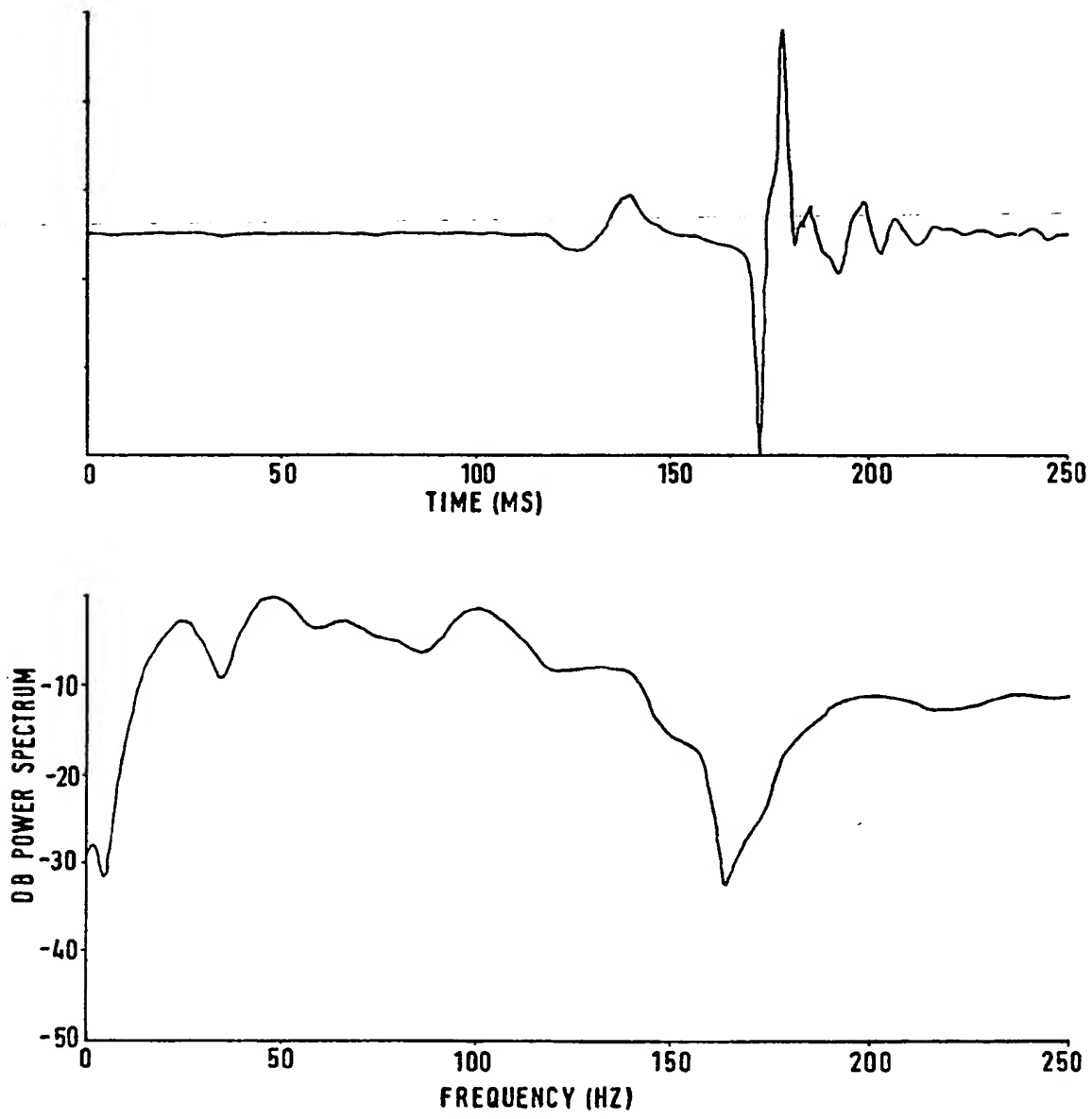

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FIG.2.

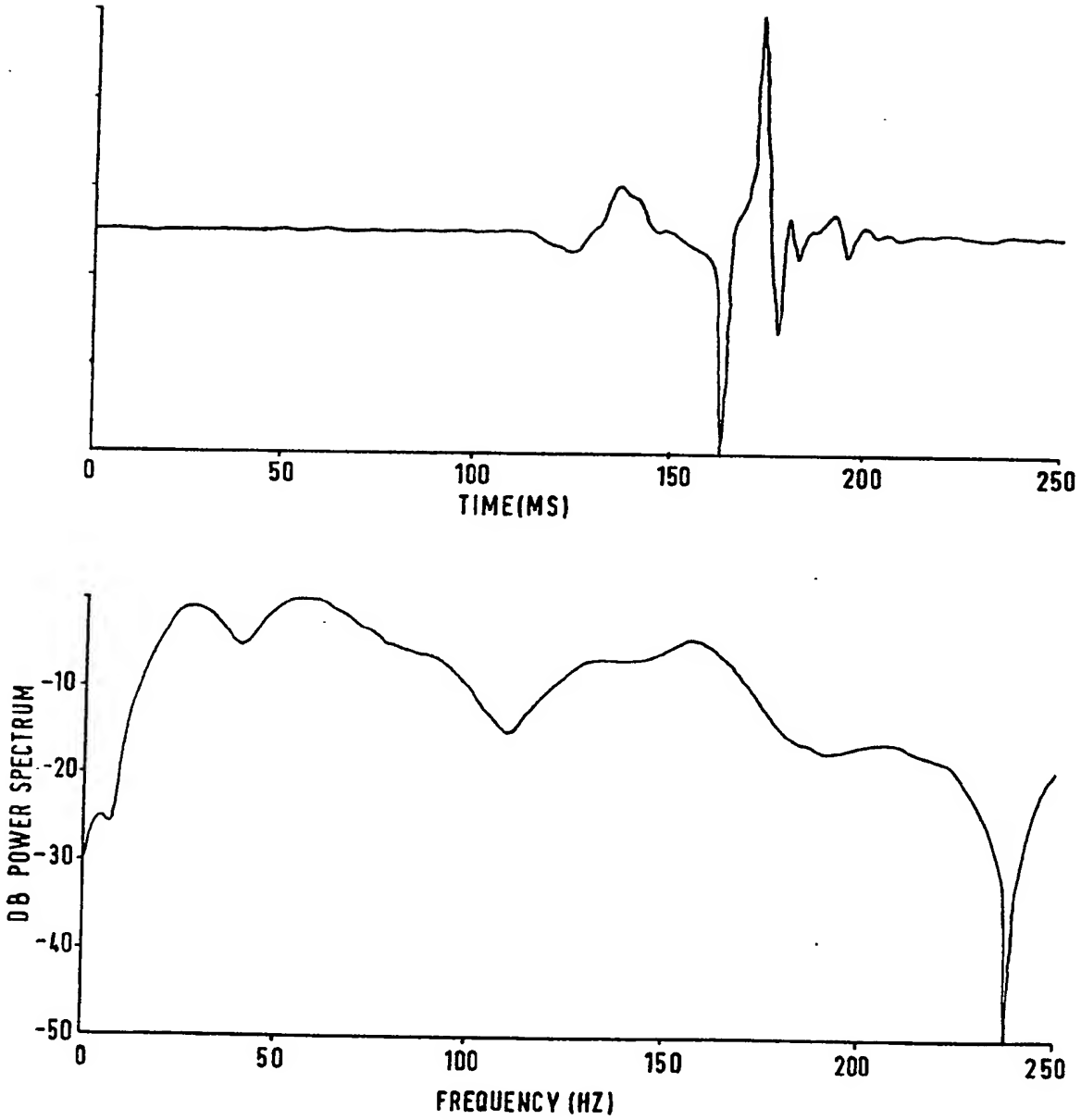

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FIG.3.

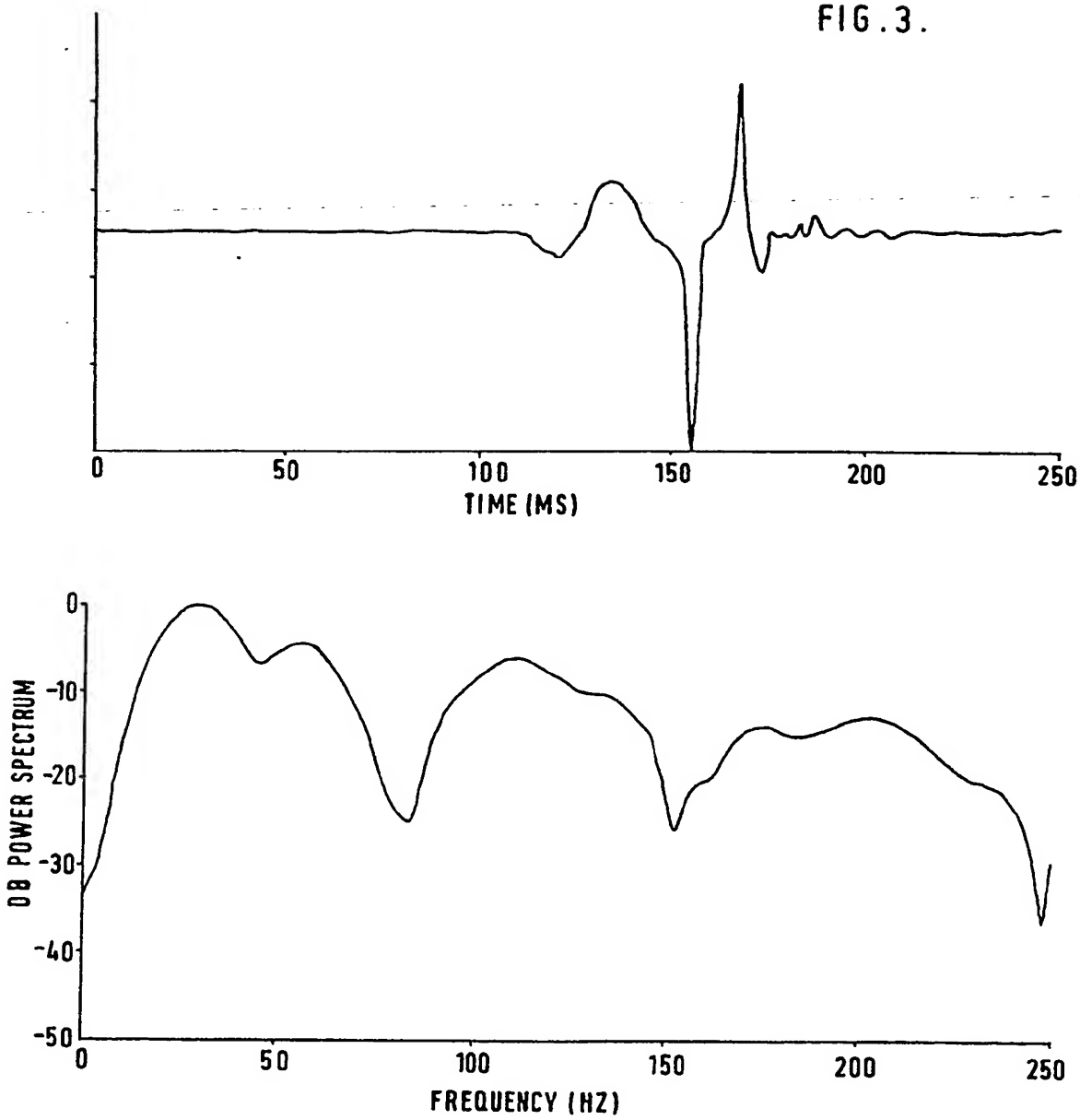

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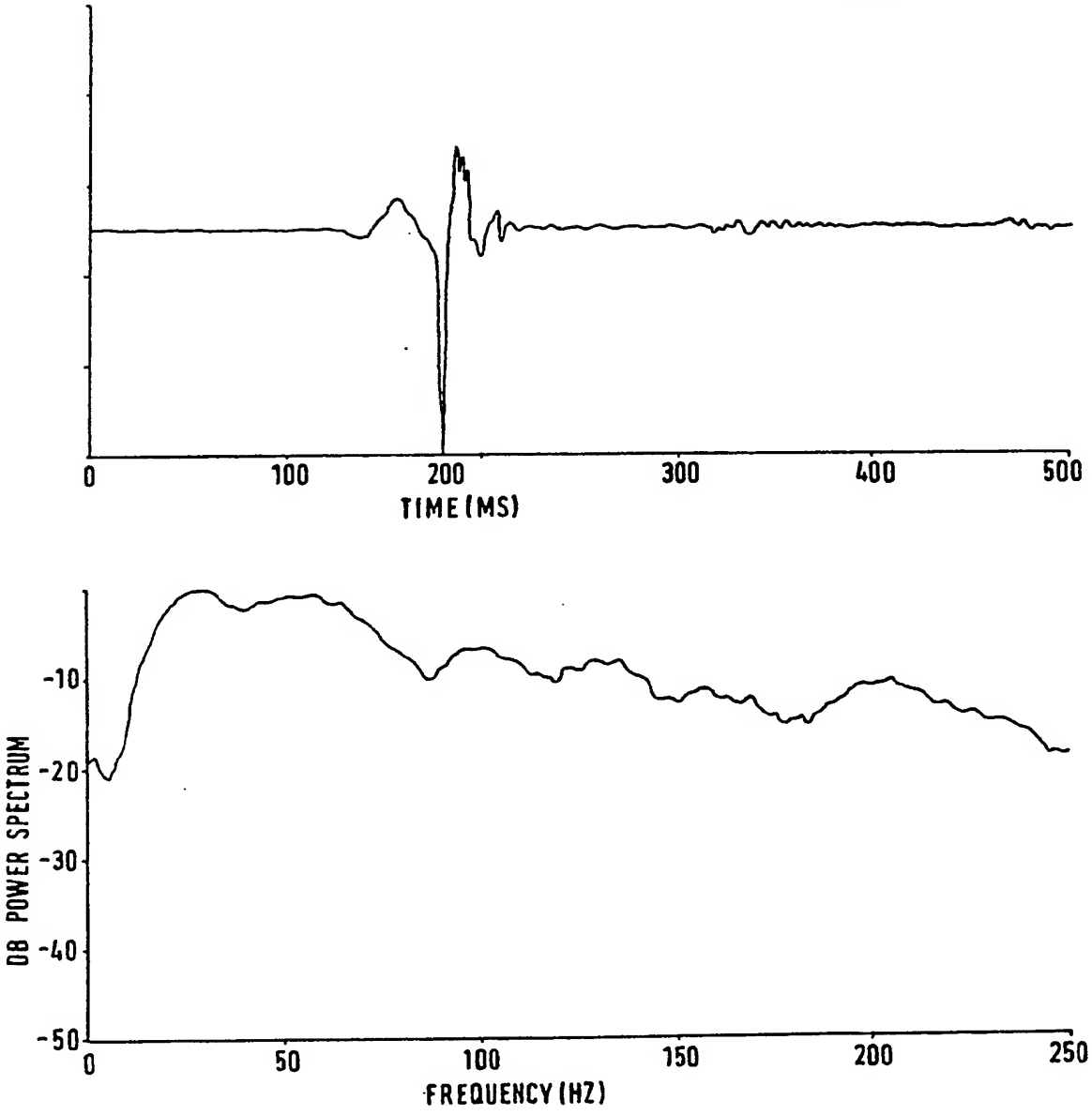
FIG.4.



SPECIFICATION

Modifying the radiated wave field of an implosive marine source

This invention relates to a method of modifying the radiated wave field of an implosive marine source.

The use of arrays of sources has been the practice in seismic exploration for many years. With air guns and other resonant sources it has been necessary to combine guns with different sizes of firing chambers in order to achieve certain desired characteristics in the radiated signal. With the development and implementation of implosive, i.e. non-resonant, sources such as the water gun it is now possible to build arrays, e.g. of water guns such that the directivity of the signal can be adjusted, whilst maintaining control of the downward radiated signal by choice of size of firing chamber or by adjusting the depth of the array.

It is well known in the industry that one factor in particular has a significant effect on the downward radiated signal. This factor is the presence of the air-sea interface above the source. This interface has a reflection coefficient of approximately -1 and therefore gives a radiating image of the same strength as the original source but of opposite polarity. The spacing between the original source and the image is controlled by the depth of the source below the surface.

The effect of the free surface is to convolve the original radiated signal with a doublet whose time spacing is twice the travel time from the source to the water surface. In general the effect of the doublet is to degrade the frequencies in the radiated signal which are required to obtain the necessary resolution of the reflected wavelet. For this reason is it normal practice to set the guns at a depth selected for minimum loss of useful energy.

An object of the present invention is to use the filtering effect of the free air water surface to produce a desirable modification of the radiated waveform.

According to the present invention there is provided a method of modifying the radiated wave field of a first non-resonant implosive marine source which comprises firing, at a known time relative to the firing of the first source, a second non-resonant implosive marine source at a depth different from that of the first source, the depth of the second source being selected such that reflections of the wav fields of the first and second sources fr m the air-sea interface above the source will at least partially cancel each other, thereby to decrease the effect of the reflection of th wave field from the air-sea interface upon the radiated wave field of the first source.

By th t rm"sourc " in the above d finition we mean either a single source or a one- or two-dimensional array in a horizontal plane of a plurality of single sources, which can be the same as or different from each other. Preferably, the same number of sources and in the same configuration should be employed as the sources at the different depths.

The term "non-resonant implosive marine source" is intended to include water guns in particular and other non-resonant sources such as those available under the Trade Marks VAPORCHOC and FLEXISHOCK.

Additional sources can be employed at third, fourth, etc. depths to further modify the radiated wave field in the required manner. For example, in a preferred embodiment identical strings of identical water guns are employed at three different depths to produce the desired far field wave field.

The respective implosive sources may be fired simultaneously, particularly if the maximum total energy is required. Alternatively, the firing of the sources may be staggered in order to shape the resultant combined pulse.

It is a considerable advantage of using the method of the present invention that the source employed at the different depths can be identical since the complications introduced by using sources of different sizes are thereby avoided. Of course, if it is preferred for some reason to use sources of different sizes at the different depths this may be done.

Generally the depth of the second source, and additional sources if present, is selected so as to minimize the effect of reflection of the wave field from the air-sea interface upon the near vertical radiated wave field of the first source. Where, however, beam starring is being employed it may be desirable to select the depth so as to minimize the above effect in the particular orientation under scrutiny.

The particular depths at which the different sources are placed can be established in any suitable manner, e.g. on a trial and error basis, or by computer synthesis based upon the combining of predetermined wave fields of individual sources (or arrays of sources) at a range of different depths, followed by an inspection of the resultant combination.

In one embodiment, a number of water guns is suspended from the surface using means which can both measure depth and adjust depth. Each gun in the array is suspended at such a depth that when the combined signals are radiated downwards then the resultant signal will have a more desirable characteristic than the single gun or a number of guns at the same depth.

An embodiment of the method of the present invention will now be described by reference to the accompanying drawings, in which:—

Figures 1 to 3 each show respectively a radiated time signal and its Fourier transform for identical guns at depths of 4.5m, 6.75m

and 9m resp ctively; and

Fig. 4 shows the radiated time signal and its Fourier transform for the combined time signals and Fourier transforms of Figs. 1 to 3.

Fig. 1 shows the radiated time signal together with its Fourier transform for a single gun at a depth of 4.5m. Figs. 2 and 3 show the same data for guns at a depth of 6.75m and 9m respectively. The combined radiated signal is shown in Fig. 4. In this example the spectrum of the single gun Fig. 1 has been modified to fill in the notch at 35 Hz and the notch at 165 Hz due to the free surface has been removed. If an array of guns with the characteristics as shown in Fig. 1 had been combined then the radiated signal would still have these undesirable features.

The depths of 4.5m, 6.75m and 9m were chosen after a computer synthesis of combinations of time signals and computed Fourier transforms to achieve the most satisfactory, flat wave form.

CLAIMS

1. A method of modifying the radiated wave field of a first non-resonant implosive marine source, which comprises firing, at a known time relative to the firing of the first source, a second non-resonant implosive marine source at a depth different from that of the first source, the depth of the second source being selected such that reflections of the wave fields of the first and second sources from the air-sea interface above the souces will at least partially cancel each other, thereby to decrease the effect of the reflection of the wave field from the air-sea interface upon the radiated wave field of the first source.

2. A method according to Claim 1, wherein one or more additional implosive marine sources each at a different depth which is different to those of said first and second sources is/are fired, at a known time relative to the firing of said first and second sources.

3. A method according to Claim 2, wherein a third source at a third depth different from the depths of said first and second sources is fired at a known time relative to the firing of said first and second sources.

4. A method according to Claim, 1, 2, or 3, wherein each said implosive marine source constitutes a horizontal one-or two-dimensional array of individual implosive marine source.

5. A method according to any preceding claim, wherein said first, second and, if present, additional implosive marine sources are identical.

6. A method according to any preceding claim, wherein the depth of said second and, if present, subsequent implosive marine sources is selected by means of a preliminary combination by computer of a number of predetermined wave fields of implosive marine sources to achieve the desired reduction in reflection effects.

7. A method according to any preceding claim, wherein the depth of the second source is selected to achieve optimum reduction in reflection effects at one or more predetermined frequencies.

8. A method according to any preceding claim, wherein each implosive marine source comprises one or more water guns.

9. A method according to any preceding claim, wherein the first, second and, if present, additional implosive marine sources are fired simultaneously.

10. A method according to any of claims 1 to 8, wherein the first, second and, if present, additional implosive marine sources are first consecutively.

11. A method according to any preceding claim, wherein the depth of the second and, if present, additional implosive marine sources is/are selected to minimize the effect of the reflection of the wave field from the airsea interface upon the near-vertical radiated wave field of the first source.

12. A method of modifying the radiated wave field of an implosive marine source, substantially as hereinbefore described.

13. A method of producing a wave field for seismic use, which method comprises firing a first non-resonant implosive marine source and firing, at a known time relative to the firing of the first source, a second non-resonant implosive marine source at a depth different from that of the first source, the depth of the second source being selected such that reflections of the wave fields of the first and second sources from the air-sea interface will at least partially cancel each other, thereby to produce a wave field, of which the reflection from the air-sea interface has been reduced.

14. A method of conducting a seismic survey which includes the use of a radiated wave field modified according to the method claimed in any one of the preceding claims.

15. The features hereinbefore disclosed, or their equivalents, in any novel selection.

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